

Systematic study of even-even $^{20-32}\text{Mg}$ isotopes

Fouad A. Majeed*

Department of Physics, College of Education for Pure Science,
University of Babylon, P.O.Box 4., Hilla-Babylon, Iraq

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A systematic study for 2_1^+ and 4_1^+ energies for even-even $^{20-32}\text{Mg}$ by means of large-scale shell model calculations using the effective interaction USDB and USDBPN with SD and SDPN model space respectively. The reduced transition probability $B(E2; \uparrow)$ were also calculated for the chain of Mg isotopes. Very good agreement were obtained by comparing the first 2_1^+ and 4_1^+ levels for all isotopes with the recently available experimental data and with the previous theoretical work using 3DAMP+GCM model, but studying the transition strengths $B(E2; 0_{g.s.}^+ \rightarrow 2_1^+)$ for Mg isotopes using constant proton-neutron effective charges prove the limitations of the present large-scale calculations to reproduce the experiment in detail.

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I. INTRODUCTION

The low energy structure of magnesium nuclei has attracted considerable interests in the last decade, both experimental and theoretical. In particular, the sequence of isotopes $^{20-40}\text{Mg}$ encompasses three spherical magic shell numbers : $N=8, 20$ and 28 and, therefore presents an excellent case for studies of the evolution of shell structure with neutron number, weakening of spherical shell closures, disappearance of magic numbers, and the occurrence of *islands of inversion* [1].

Extensive experimental studies of the low-energy structure of Mg isotopes have been carried out at the Institute of Physical and Chemical Research, Japan (RIKEN) [2, 3], Michigan State University (MSU) [4, 5, 6, 7], the Grand Accélérateur National d'Ions Lourds, France (GANIL) [8] and CERN [9, 10].

In addition to numerous theoretical studies based on large-scale shell-model calculations [11, 12, 13, 14, 15, 16], the self-consistent mean-field framework, including the nonrelativistic Hartree-Fock-Bogolibov (HFB) model with Skyrme [17] and Gogny forces [18] and the relativistic mean-field (RMF) model [19, 20] as well as the macroscopic-microscopic model based on a modified Nilsson potential [21], have been used to analyze the ground-state properties (binding energies, charge radii, and deformations) and low-lying excitation spectra of magnesium isotopes.

The purpose of present work is to study the ground state 2_1^+ and 4_1^+ excitation energies and the reduced transition probabilities $B(E2; 0_{g.s.}^+ \rightarrow 2_1^+)$ (e^2fm^4) of the even-even $^{20-32}\text{Mg}$ isotopes using the new version of Nushell@MSU for windows [22] and compare these calculations with the most recent experimental and theoretical work.

II. SHELL MODEL CALCULATIONS

The calculations were carried out in the SD and SDPN model spaces with the USDB and USDBPN effective interactions [23] using the shell model code Nushell@MSU for windows [22].

The core was taken as ^{16}O with 4 valence protons and 4,6,8,10,12,14,16 valence nucleons for ^{20}Mg , ^{22}Mg , ^{24}Mg , ^{26}Mg , ^{28}Mg , ^{30}Mg and ^{32}Mg respectively distributed over $1d_{5/2}$, $1d_{5/2}$ and $2s_{1/2}$.

The effective interaction USDB with model space SD where used in the calculation of the $^{20-30}\text{Mg}$ isotopes, while USDBPN in pn formalism where employed with SDPN model space for ^{32}Mg nucleus.

III. RESULTS AND DISCUSSION

The test of success of large-scale shell model calculations is the predication of the low-lying 2_1^+ and 4_1^+ and the transition rates $B(E2; 0_{g.s.}^+ \rightarrow 2_1^+)$ using the optimized effective interactions for the description of *sd*-shell nuclei.

Figure 1 presents the comparison of the calculated $E_x(2_1^+)$ energies from the present work (P.W.) with the experiment [24], the work of J. M. Yao *et al.* [25] using 3DAMP+GCM model with the relativistic density functional PC-F1.

The comparison shows that our calculation are in better agreement with the experiment than the work of Ref.[25]

Figure 2 shows the comparison of the calculated low-lying $E_x(4_1^+)$ excitation energies from present work (P.W.) with the experiment [24], the work of J. M. Yao *et al.* [25] using 3DAMP+GCM model with the relativistic density functional PC-F1. The comparison shows very clear that our prediction for the $E_x(4_1^+)$ are in better agreement with the experiment.

Figure 3 presents the comparison of the calculated $B(E2; 0_{g.s.}^+ \rightarrow 2_1^+)$ (e^2fm^4) from present work (P.W.) with the experimental data taken from the Institute of

*Electronic address: fouadalajeeli@yahoo.com

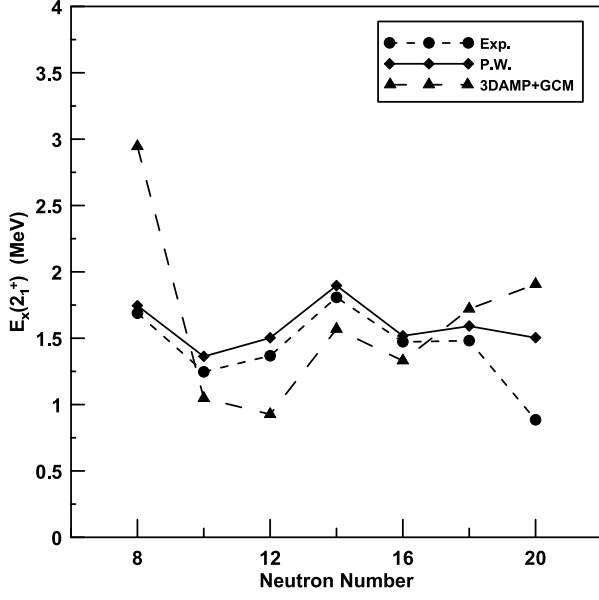


FIG. 1: Systematics of $E_x(2_1^+)$ for even-even Mg isotopes. Experimental data (closed circles) are compared with present work (solid line), the previous work using 3DAMP+GCM model (long dashed line). Experimental data are taken from Ref.[24].

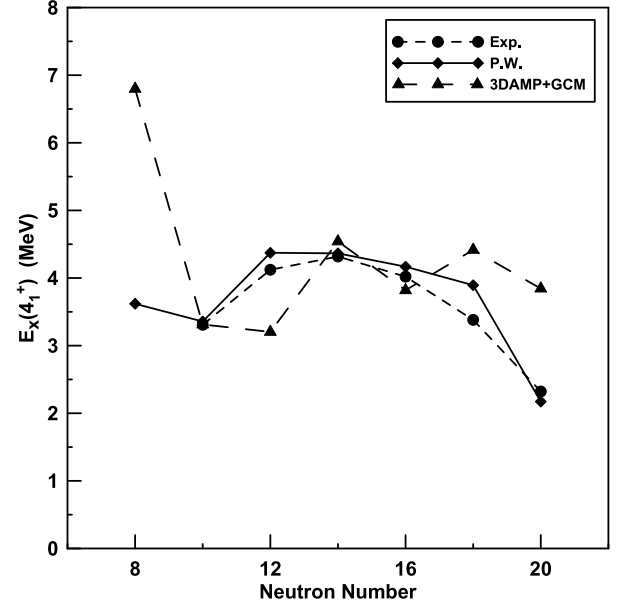


FIG. 2: Systematics of $E_x(4_1^+)$ for even-even Mg isotopes. Experimental data (closed circles) are compared with present work (solid line), the previous work using 3DAMP+GCM model (long dashed line). Experimental data are taken from Ref.[24].

Physical and Chemical Research, Japan (RIKEN) [2, 3], the Grand Accélérateur National d'Ions Lourds, France (GANIL) [8] and CERN [9, 10], the previous theoretical work of J. M. Yao *et al.*[25] using 3DAMP+GCM model and with the work of R. Rodríguez-Guzmán *et al.*[18] using HFB-Gogny force. The effective charges were taken to be $e_\pi=1.25e$ for proton and $e_\nu=0.8e$ for neutron. With these effective charges our prediction for the reduced transition probability $B(E2; 0_{g.s.}^+ \rightarrow 2_1^+)$ are more closer to the experimental values than the previous work of Refs. [18, 25].

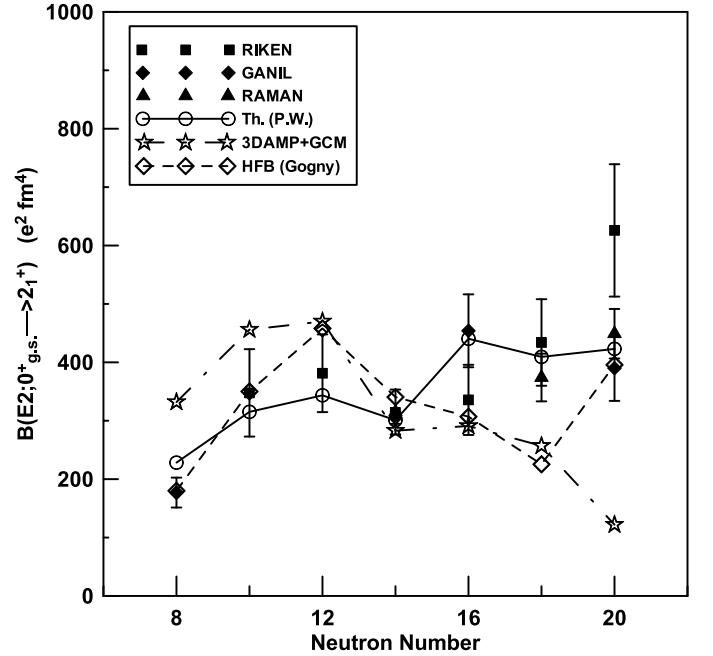


FIG. 3: Comparisons between the calculated $B(E2; 0_{g.s.}^+ \rightarrow 2_1^+)$ ($e^2 \text{fm}^4$) of the even-even $^{20-32}\text{Mg}$ isotopes (solid line) (P.W.), 3DAMP+GCM model (dashed-dotted line)[25] and HFB (Gogny)(dashed line) [18]. Experimental data taken from Refs. [2, 3, 8, 9, 10]

IV. SUMMARY

Unrestricted large scale-shell model calculations were performed using the effective interactions USDB and US-DBPN in pn formalism with the model space SD and SDPN to study the low lying 2_1^+ and 4_1^+ energies for even-even $^{20-32}\text{Mg}$ isotopes and the transition strengths

$B(E2; 0_{g.s.}^+ \rightarrow 2_1^+)$ for the mass region $A=20-32$. Good agreement were obtained in comparing our theoretical work with the recent available experimental data and with the most recent theoretical work of Ref.[25] using 3DAMP+GCM model with the relativistic density functional PC-F1 for both excitation energies and transition strengths.

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